OPTICAL FIBER TEMPERATURE SENSOR BASED ON FIBER BRAGG GRATING

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Thank to my Gad

Thank to my family

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ABSTRACT

It is important to study optical fiber temperature sensor based on fiber Bragg Grating. The Fiber Bragg grating sensors can offer highly sensitive, cost effective solutions for optical sensing. While fiber Bragg gratings have been implemented in various sensing applications over the past few decades, recent efforts explore the limits of reflected and transmitted for FBG sensors. The FBG temperature sensor, is essential to establish the smallest distance of single mode fibre in order to reduce optical losses of the FBG system. One of the most generally used deployed optical sensors is the fiber Bragg grating, with optical circulator, ASE source and OSA, the FBG which reflects a wavelength of light that shifts in response to variations in temperature. The advantage of reflection that its can easily detect the Bragg reflected signal. The FBG is very sensitive to variations in temperature degrees over a temperature range of (30–60) °C. The variation of wavelength of an fiber Bragg grating is caused by the temperature. Moreover, change in temperature affect both the effective refractive and grating period of an FBG, which result in a shift in the reflected wavelength. Moreover, most of the existing FBG sensors systems on the market provide a limited wavelength resolution Therefore, it is the purpose of this thesis to enhance the grating sensors sensitivity to temperature. In addition, the purpose to make a small comparison between the transmitted and reflected spectrum. It is apparent that any shift in the Bragg wavelength is influenced by the temperature. Moreover, the sensitivity was calculated equal to 17.1pm°C with SNR equal to 13.7 dB based on the reflection spectrum.

ABSTRAK

Adalah penting untuk mengkaji sensor suhu gentian optik berdasarkan gentian Bragg Grating. Sensor grinding Fiber Bragg boleh menawarkan penyelesaian yang sangat sensitif, kos efektif untuk penderiaan optik. Walaupun serat Bragg gratings telah dilaksanakan dalam pelbagai aplikasi penderia sejak beberapa dekad yang lalu, usaha baru-baru ini meneroka had-had yang dicerminkan dan dihantar untuk sensor FBG. Sensor suhu FBG, adalah penting untuk menubuhkan jarak terkecil gentian mod tunggal untuk mengurangkan kehilangan optik sistem FBG. Salah satu sensor optik yang digunakan secara umum ialah gentian Bragg serat, dengan peredaran optik, sumber ASE dan OSA, FBG yang mencerminkan panjang gelombang cahaya yang beralih sebagai tindak balas kepada variasi suhu. Kelebihan pantulan dapat dengan mudah mengesan isyarat yang ditunjukkan oleh Bragg. FBG sangat sensitif kepada variasi dalam darjah suhu di atas julat suhu 30-60 ° C. Variasi panjang gelombang gentian Bragg serat disebabkan oleh suhu. Lebih-lebih lagi, perubahan suhu memberi kesan kepada kedua-dua tempoh refraktif dan penyejukan FBG yang berkesan, yang menyebabkan pergeseran panjang gelombang yang dicerminkan. Lebih-lebih lagi, kebanyakan sistem sensor FBG sedia ada di pasaran menyediakan resolusi panjang gelombang had Oleh itu, tujuan tesis ini untuk meningkatkan sensor pengisar menunjukkan kepekaan terhadap suhu, Juga, untuk membuat perbandingan kecil antara spektrum yang dihantar dan dicerminkan. adalah jelas bahawa sebarang perubahan dalam panjang gelombang Bragg dipengaruhi oleh suhu. Dan sensitiviti dikira sama dengan 17.1pm ° C dengan SNR bersamaan dengan 13.7 dB berdasarkan spektrum pantulan.

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LIST OF SYMBOLS AND ABBREVIATIONS

SHM	Simple Harmonic Motion
LPG	Long Period Grating
PCF	Photonic Crystal Fiber
CTE	Coefficient of Thermal Expansion
RTD	Resistance Temperature detectors
FBG	Fiber Bragg Grating
OSA	Optical Spectrum Analyzer
FOS	Fiber Optic sensor
FDM	Frequency Division Multiplexing
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
UV	Ultraviolet
ASE	Amplified Spontaneous Emission
EDFA	Erbium Doped Fiber Amplifier
RI	Refractive Index
STCS	Single mode Taped Cladding-less Single mode
SNR	Signal to Noise Ratio
MZI	Mach–Zehnder Interferometer
SMF	Single Mode Fiber
FRL	Fiber Ring Laser
SOFO	Surveillance d'Ouvrages par Fibers Optiques

CHAPTER 1

INTRODUCTION

1.1 Research Background

In general, sensors are instruments that are responsible for detecting events or changes in their environment and presenting the corresponding output. The sensor can provide various types of output, the output could be an electrical signal or an optical signal. Optical fiber sensor technology is a direct result of the revolution in optoelectronics and fiber optic communications[1]. The most common type of all sensors is a sensor that detects temperature or heat. Such temperature sensors can range from ON/OFF thermostats for controlling domestic hot water heating to the most sophisticated temperature sensors with highly sensitive semiconductor types, which can control and control the complex processes of furnace plants. There are many differences between various types of temperature sensor devices.

Moreover, in the recent era fiber optic temperature sensors have been deeply studied because they provide several compensations, such as: electromagnetic interference, stability and high sensitivity in harsh surroundings [2]. Many innovations in the optoelectronics and optical fiber communications industry over the past two decades have reduced the price of optical devices and improved their quality. Considering all these economies of scale, fiber optic sensors and related instruments have been transformed from experimental research applications in the laboratory to widespread use and applicability in field applications such as structural temperature, strain, and health monitoring. In addition, these sensors are able to be used for other changed usages such as food heat treatment [3], health monitoring and aviation (aeronautics).

The deployment of currently available fiber-optic sensors based on fiber Bragg gratings (FBG) is costly. The main cost in the setup stems from the need to identify changes in the sensor's reflection wavelength. Cost-introducing elements with FBG sensors are typically very small wavelength variations characterized by amplitudes measured in picometers (10-12 meters)[4], [5]. Therefore, an optical spectrum analyzer (OSA) deployed at the end of the fiber needs to be sufficiently advanced to distinguish this change, an installation technique of FBG sensors has been studied to fulfil the special requirements. The experiment setup of the FBG temperature sensor work are based on transmitted and reflected. The system includes light source, FBG, circulator, optical spectrum analyzer (OSA) and PC. The light into the fiber core, part of the light that meet the Bragg condition will then reflect back through the circulator and enter the OSA.

Therefore, several methods have been demonstrated, such as fiber taper, long period grating (LPG), multimode interference (MMI) and fiber Bragg grating (FBG) [6]. Among them, fiber Bragg gratings are principally superior for detecting products because of their interesting properties, such as their versatility and high sensitivity for wavelength-coded appliances. In fact, a great number of FBG-based temperature sensors can be found in the literature

1.2 Problem Statement

Temperature has been chosen to study because most of industrial processes are influenced by temperature. In order to get the desired response or output with accuracy. this issue could be increasing when the apply in a strong electric-magnetic fields. In this thesis we have compared the FBG sensors based on the transmitted and reflected spectrum. Based on designing an FBG sensor. Because of there is little focus on that in previous studies. When designing an FBG sensor it’s important to ensure the Bragg wavelength drift of the unit parameter of the measured parameter is large enough to be solved by the FBG inspection system. Most of the existing FBG sensors systems on the market provide wavelength resolution around 1 pm. The authors in [7] designed and developed a temperature sensor using a commercial FBG and proved the sensor has an average sensitivity of 9.1 pm/°C. While the author in [8], improved the accuracy of FBG sensor to 0.01◦C, the sensitivity for FBG can be accurate by dielectric temperature sensors [8]. Therefore, from the previous study in this thesis we make the comparison of FBG sensors based on the transmitted and reflected spectrum it should be optimized by considering the balance amongst sensitivity and physical reliability. The experiment with different temperatures were conducted to demonstrate the effectiveness of the system. The FBG sensors satisfy the shift wavelength for transmitted and reflected, when the temperature changed from 30◦C to 60 ◦C in order to adjust the accuracy of the sensors.

1.3 Objectives

The aim of this project is to propose, design and characterize a suitable optical fiber temperature sensor based on fiber Bragg grating.

The following are the objectives of this project:

1.3.1 To investigate of temperature effect on the fiber Bragg grating (FBG).

1.3.2 To make comparison of FBG sensors based on the transmitted and reflected spectrum.

1.3.3 To verify the optical fiber temperature sensor of FBG fabricate based on the transmitted and reflected to obtain the accurate temperature measurements with enhanced the sensitivity.

1.4 Scope of Study

The scope of the project focuses the design of optical fiber temperature sensor depend on fiber Bragg grating, which represent as follows:

i) To study the temperature effect on the fiber Bragg grating.

ii) To investigate the optical fiber temperature by using the FBG wavelength shift from an OSA and compute the equivalent temperature change using LabVIEW.

iii) To evaluate the thermal response of FBG for linear relationship between temperature and the wavelength with experimental result.

1.5 Contents of chapters

In this part we will explain the summary for all chapters. Chapter one explained the optical fiber temperature sensor based on fiber Bragg Grating. Moreover, the chapter one study the effect of the temperature sensitivities has been evaluated individually through determine the problem statement and apply the new suggestion in section the objective of study to shown the Bragg reflected and transmission spectrum.

Chapter 2 describe the literature reviews related to the fiber Bragg grating. The items of discussion are about typical low-cost type related to the optical fiber sensor based of fiber Bragg grating application project. Also, this chapter describe the sensor classification and advantage and disadvantages of the fiber Bragg grating. There is also a discussion the types of gratings and temperature sensing on the outcome result from previous studies journals, and articles.

Chapter 3 achieve the objective through used the proposed methodology for flow chart that explain setup experiment and obtain the good performance. Also, this chapter describe the FBG working principle and calculation through explain all the equations that have more related to estimate the reflective and transmitted of FBG sensors. In addition to, this chapter explains the important of used two of OSA for both reflected and transmitted in the design procedure. Specifically, the standard of the FBG temperature sensor is relied on the measurement of the Bragg wavelength shift corresponding to the temperature change. Finally, this chapter describe the experiment advantage and summary.

Chapter 4 the results and discussion in chapter four can be explain by used two stages, the first stage explains the experiment result. Second step analyse the results based on varying the temperature from 30◦C to 60 ◦C for both transmitted and reflected and the sensitivity of FBG temperature

Chapter 5 explain the conclusions and future works based on previous result that is evaluated in chapter four.

1.6 Summary

This chapter describe the introduction to optical fiber temperature sensor and specially of fiber Bragg grating (FBG) is stated. The objectives are obviously identified. The problem statement of the project is outlined and the scope is evident as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explain the literature reviews related to this project. The entries of analysis are around what other people have done related to the optical fiber sensor based of fiber Bragg grating application thesis. In addition, it explains the previous result from other journals, articles and books.

Low-loss fibres are used for sensing purposes and not for telecommunications, which was the intended purpose of its development since the early 1970s. This led to the development of a new technology and triggered a new field of research for researchers. Since then, the field of fiber optic sensors has continued to advance and a series of fiber-based sensors have been enhanced [9]. Hence, fiber optic sensors can be defined as sensors that use fiber optics as sensing elements, or signals from remote sensors to electronic devices that process signals. The main driving forces for the study of fiber optic sensors (such as FBG sensors), for example, provide advantages for various applications provided by other types of sensors. They are small and lightweight and can be used for remote sensing because no power is needed at remote locations. Generally, they are minimally invasive and able to be multiplexed on a single fiber network. This permits for multiple sensing points and, more importantly, is essentially passive. Not affected by electromagnetic interference, they can be used in places with high electric fields or flammable materials (potentially explosive environments) [10].

2.2 Research Theory and Require

Fiber Bragg Grating (FBG) technology is one of the most popular choices for optical fiber sensors for temperature measurements due to their simple manufacture, will see later on, and due to the relatively strong reflected signal [11]. The good function and operation of equipment or industrial, chemical and medical processes are affected by temperature changes. The rate at which the reaction occurs is affected by temperature. Many industrialized devices have a specific operating temperature range beyond which the equipment fails. For example, power transformers, motors, antennas, power plants, etc., are all departments that monitor temperature. For example, transformers are important for the transmission, distribution and utilization of electrical energy in daily life. It is estimated that about 30% of power transformers fail due to insulation and overload [12].

From a cooling point of view, the rule of thumb accepted by us is that the insulation life of all electrical equipment, including all transformers, is halved, and the operating temperature is reduced by half for every 7°C to 10°C increase. Prolonged operation at high temperatures reduces the insulating properties of the winding insulation and the dielectric coolant, which not only shortens the service life of the transformer, but also ultimately leads to catastrophic transformer failure [13]. Consequently, the capability to sustain a steady temperature inside the transformer is significant to the life of the device.

This requires the development of tools and equipment that can accurately measure these temperature changes in order to fully and selectively respond to these temperature changes. This has led to the improvement of a variety of thermometers and sensors. These range from classic glass mercury thermometers to specialized sensors such as RTD sensors, thermocouples, semiconductor PN-junctions, optical temperature sensors, fiber optic sensors, optical temperature sensors, acoustic temperature sensors, and piezoelectric temperature sensors [14]. Among them, thermocouples are the most widely used electronic temperature sensors in science and industry [8], [15]. They are passive sensors that generate voltages and self-powered based on temperature. two major limitations of thermocouples that is their limited accuracy. Sensitive for systematic errors less than 1 degree Celsius (C) may be not easy to accomplish [15]. This means that it is virtually impossible to repeatedly measure temperature changes that are less than one degree. In addition, because their operation relies on measuring very small voltage changes, voltage changes involving high electric fields will be interpreted as temperature changes. This means that they cannot be used near electric fields. Nevertheless, applications in the electric power utility industry, such as power transformers, motors, antennas, and power plants are critical sectors that monitor temperature as previously mentioned. Therefore, high sensitivity and dielectric temperature sensors are required to accurately measure the temperature of transformers or high electric fields.

Figure 2-1: Characteristic low-price type K thermocouple (with typical style K connector) [15]

However, measuring very small temperature changes is still a problem with existing FBG sensors. The standard FBG sensor has an accuracy of about 0.1C. This means that measuring a slight temperature change below 0.1 degrees is virtually impossible. The relatively low accuracy can be attributed to the low factor of thermal extension of the glass -0:55 10 6 C-1, which makes the FBG less sensitive.

Based on order to effectively use the temperature impact on the FBG sensor, the thermal sensitivity must be increased. This is already a research area for different research teams, and different approaches have been suggested to improve the thermal.

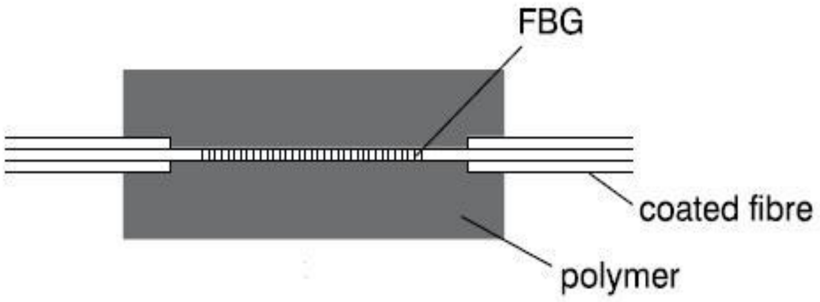

Figure 2-2: Polymer on the FBG improves its thermal sensitivity [15].

Sensitivity of FBG sensors. The use of optical signal post-processing showed that the thermal sensitivity of the FBG increased to 54.09 pm/°C. Sensitivity development is achieved through degenerate four-wave mixing for frequency chirp amplification that could be utilized to amplify wavelength drift induced by FBG sensors through temperature variation [7], [15]. The most common technique for increasing the temperature sensitivity of FBG sensors is to coat the latter with high thermal expansion coefficients [10], [14].

In [14], H. Mavoori et al. proposed a mechanical configuration to improve the thermal sensitivity of FBG for use with fiber Bragg grating-based reconfigurable add-drop policies using coatings of special metal alloys. On one side of the FBG, a Ti-Ni alloy having a negative thermal expansion factor was adhered to the fiber, and an aluminium alloy having a positive thermal expansion coefficient was used on the other side. When heated, the negative CTE assembly shrinks while the positive CTE assembly expands; causing superimposed temperature-dependent tensile strain in the FBG, resulting in a large wavelength shift compared to the bare FBG. In [14] it is reported that thermal sensitivity increases to 100pm/K. Jinu Paul et al. By etching the cladding on the FBG and coating the portion with a polymer, high thermal sensitivity can be achieved. Although these polymer coatings have higher sensitivity than metal coatings, they generally degrade at temperatures above 200°C. Therefore, they cannot be used for high temperature applications such as transformers.

2.3 Type of Fiber Optics Sensor

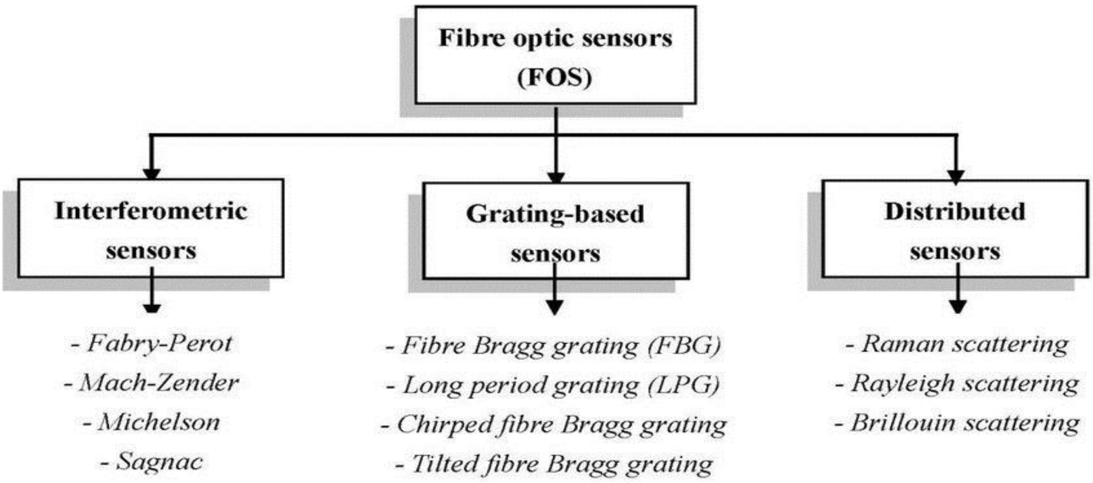

Figure 2-3: Overview of basic principles and types of fibre optic sensors.

The operation of interferometric sensors is based on the change of the optical phase difference between two light waves with the same frequency, caused by the variation of a physical quantity. The major advantage related to the use of the interferometric principle is the high resolution that can be achieved which, for example, can exceed 1 με for strain measurement. Sensors based on the Mach-Zender, and Michelson interferometers, also using long period gratings (LPGs) and photonic crystal fibres (PCFs), have been used preferably for refractive index temperature or velocity measurement. while the Sagnac interferometer has been applied mainly to rotation measurements. However, some of the first applications of fibre optic sensors for structural health monitoring, conducted by McDonnell Douglas in the 1980's, used the Sagnac interferometer as a strain sensor. Fabry-Perot and low coherent (SOFO) interferometric sensors are the most successful interferometric sensors that have been applied as yet to strain and strain-related monitoring applications. Fabry-Perot sensors can attain a resolution as high as 0.15 με and a measurement range that can extend to ±5000 με. They are small with a length ranging from 1 to 20 mm and hence can be integrated into a structure without affecting its mechanical properties significantly; moreover, they can withstand temperatures of up to 250 °C. The major disadvantage related to the use of the mentioned interferometric sensors for structural health monitoring purposes is their low multiplexing capability, which limits their application to the measurement of a relatively low number of points. SOFO sensors using lowcoherence interferometry have been applied with success to a wide range of SHM applications, from bridges to oil pipes. Unlike Fabry-Perot sensors, SOFO are long-gauge sensors with lengths that are typically in the centimetre range while offering micrometre resolution. In addition, they are insensitive to temperature, highly precise and stable. However, their dynamic measurement range is quite low, only up to 1 Hz. This limitation makes them unsuitable for the detection of dynamic strains during operational loading, and for fatigue or the impact damage monitoring of aircraft structures [16].

2.4 Fiber Optic Sensor Applications

Following the fast development of the optical fiber sensor technology in recent years, many kinds of optical fiber sensors have been designed and developed to measure various parameters. To date, more than 70 different parameters could be measured or monitored by optical fiber sensors, such as rotation, acceleration, electric and magnetic fields, temperature, pressure, acoustics, vibration, strain, humidity, viscosity, refractive index, etc. Optical fiber sensors have become more and more important, and in many industries, they gradually become indispensable, such as in civil, medical and military applications.

2.4.1 Civil Applications

- **Oil and Gas**

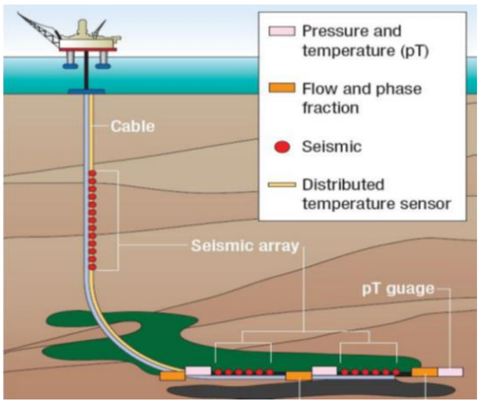

Figure 2-4: Optical sensor in Oil and gas reservoirs [17]

First of all, optical fiber sensors have become very important tools in the oil and gas industry, helping engineers not only locate and monitor the wells, but also extract the largest possible percentage of oil and gas out of them. Within oil or gas wells, the environmental conditions are challenging with temperature over 100 oC and sometimes even as high as 200 oC. The reliability of conventional electrical sensors decreases under such harsh environment, and the electrical sensors may even increase the possibility of explosion inside the oil or gas wells. The reason that optical fiber sensors could offer high reliability for in-well applications is their passive nature. Today, the optical fiber sensors available to the oil and gas industry are intrinsic, that is, the sensing element is the fiber itself and the light does not have to exit and re-enter the fiber core. Hence, after the first optical fiber sensor based on fiber coupled micro-machined silicon resonators was installed in an oil well in 1993 for temperature and pressure measurement [17], many pressures, temperature, flow and seismic sensors have been installed in reservoirs permanently over the past 20 years. Such optical fiber sensors are widely used to map reservoirs, image and characterize the geophysical properties of rock formations, and to monitor the processes separating oil, gas and temperature.

- **Aviation transport lines**

Figure 2-5: The Airbus A380[17]

Secondly, the health of some massive structures, such as aircrafts, wind-turbine blades, bridges, dams, etc. needs to be monitored in a continuous manner to avoid some disaster accidents. For example, researchers in Germany have tested optical fiber sensors based on Bragg gratings in the tail of the new Airbus A340/600, and Airbus is actively investigating the use of optical fiber sensors on the A380 [17]. Embedded into the structure of the aircraft, optical fiber sensors which could measure strain offer the

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